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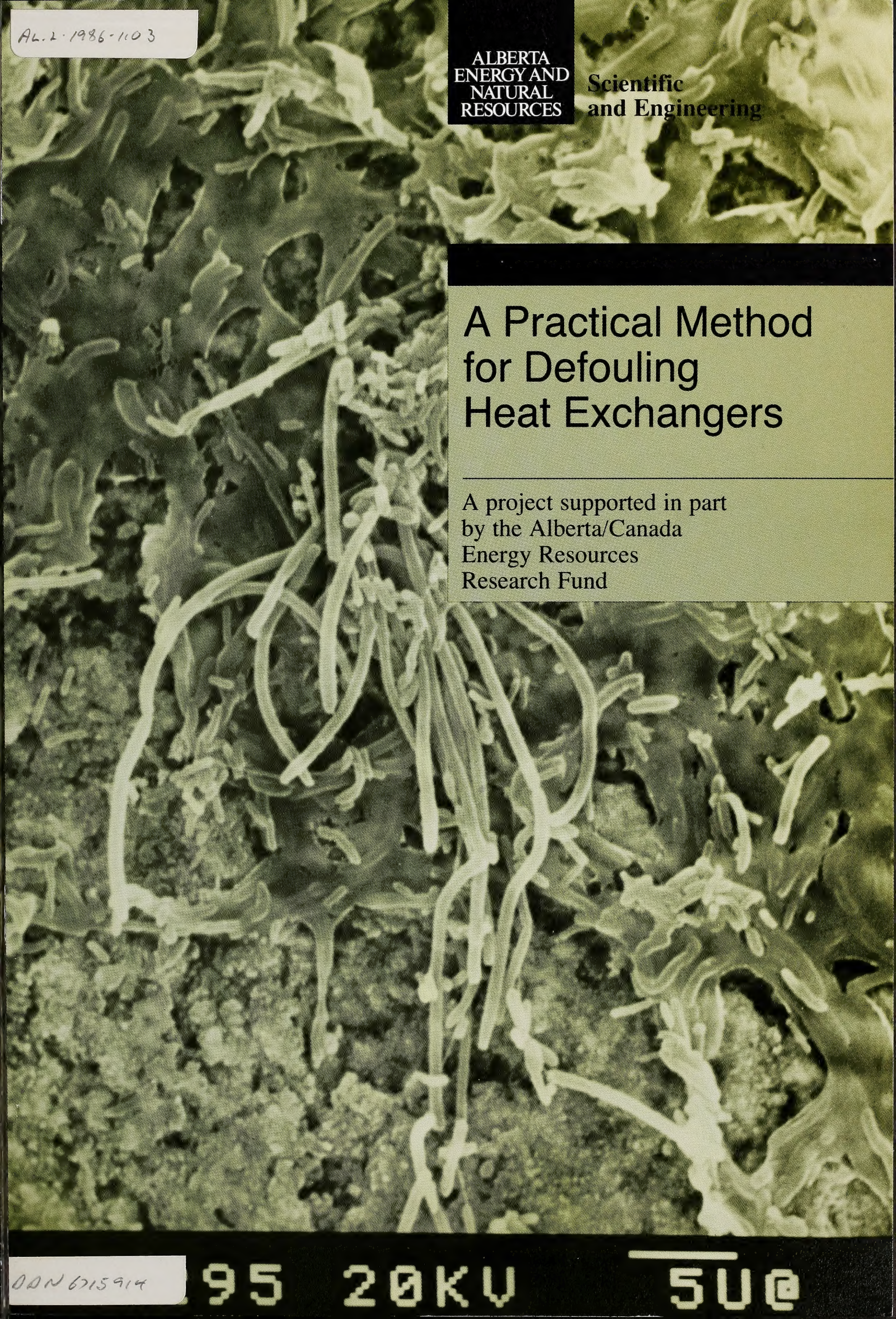

ALBERTA
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RESOURCES

Scientific
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A Practical Method for Defouling Heat Exchangers

A project supported in part
by the Alberta/Canada
Energy Resources
Research Fund

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Cover Photo: Whenever untreated water is used in heat exchangers, slimy films of bacteria (here magnified several thousand times in a scanning electron micrograph) form on interior metal surfaces. These "biofilms" impede water flow and reduce heat exchange capacity to such an extent that cleaning procedures are required.

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ENERGY AND
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Scientific and Engineering
Services and Research Division

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal, energy conservation and renewable energy and conventional energy resources. Administration for the program is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy and Natural Resources.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to the inside back page.

A Practical Method for Defouling Heat Exchangers

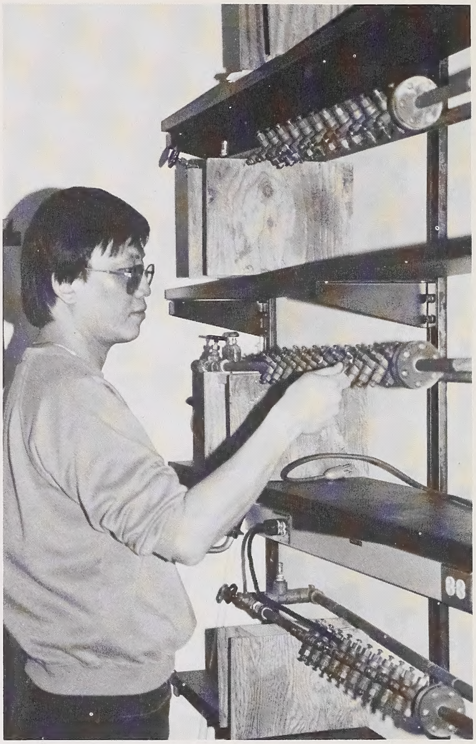
When untreated water is used in heat exchangers — whether in industry, thermal power generating stations or small-scale heating plants — a slimy film of bacteria often forms inside the water-filled tubes. This "biofilm", as it is called, causes reduced rates of flow and results in a loss of heat exchange capacity. In the past, bacteria were effectively removed by chlorination but concerns about the impact of chlorine on receiving waters have caused its use to be curtailed. Subsequently, many chemical biocides were tried in place of chlorine to kill bacteria but they have not been as effective. Therefore, the ongoing need to discover a cost-effective method of removing biofilms from fouled heat exchangers was regarded as an appropriate subject for an A/CERRF-funded investigation.

Previous Discoveries

Before this project was begun, the principal researcher, Dr. J.W. Costerton of the University of Calgary, and his associates had studied bacterial growth in many aquatic systems. They found that most bacteria stick to submerged surfaces — such as rocks in a stream — by means of an outwardly extending mass of tangled fibres — or matrix — comprised of polysaccharides. This felt-like film is called a "glycocalyx". It surrounds individual cells or colonies of cells and it can tenaciously adhere to surfaces like metal, plastic or human tissue.

Previously, it was mistakenly believed that bacteria in aquatic systems existed as loose populations. Therefore, biocides that were developed to kill them were assessed on their ability to destroy floating bacteria. As it turned out, this was a poor indication of a biocide's ability to remove biofilms and, indeed, most biocides were found to be only partly effective in cleaning fouled surfaces.

Because chlorine use is discouraged and alternative chemicals proved to be disappointing, mechanical techniques have been tried such as scrubbing fouled surfaces with abrasive materials. This approach, too, was found to be unsatisfactory, primarily because it is expensive and is also thought to be too labour-intensive.



Robbins Devices arrayed at University of Calgary to monitor bacterial fouling of metal surfaces.

Study Approach

In order to quantify the defouling capabilities of biocides and other, alternative techniques that might arise from this investigation, the researchers invented a biofilm sampler called the "Robbins Device" which allowed measurement of the progressive buildup of biofilm on a metal surface and the effectiveness of various techniques in removing it.

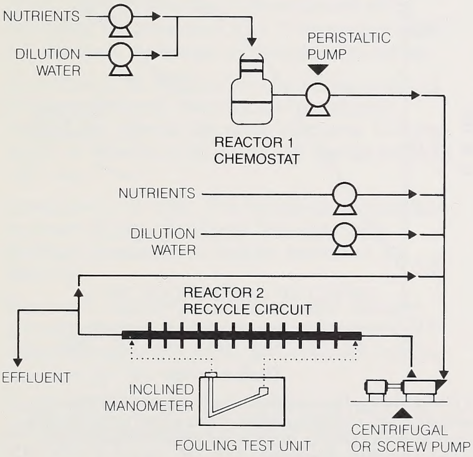
The device, which is a one inch diameter pipe having a series of removable metal studs set into its walls, provides defined areas of metal surface on which biofilm can develop and then be removed for examination by various measurement tools such as a scanning electron microscope (SEM).

Results

Results from the two-phase study were reported in two documents submitted to the A/CERRF Committee. They were: "Control of Energy and Production Losses Caused by Biofouling of Heat Exchangers and Industrial Water Systems" and "Modification of the Ice Nucleation Technique to Produce A Practical Method for Defouling Heat Exchangers".

The researchers observed that the passage of bacteria-containing water through the Robbins Device caused it to become fouled in two to three weeks. After fouling had occurred, various solutions of biocides were passed through the Robbins Device to determine their effectiveness in removing biofilms. The laboratory results confirmed the general observations reported by industry that commercial biocides — except chlorine — are seldom cost-effective in killing adherent bacteria and are not cost-effective in removing biofilms.

The investigators postulated that chlorine is an effective defouling agent because it oxidizes the polysaccharide mass which subsequently breaks up. But biocides are unable to penetrate the polysaccharide matrix and, therefore, they have little effect on the biofilm.



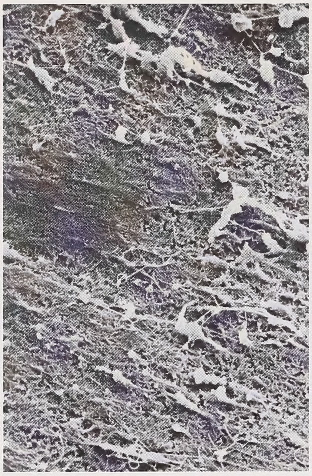
A typical laboratory arrangement used to produce bacterial fouling. An inclined mercury manometer measured changes in fluid frictional resistance as biofilms developed or were destroyed by Ice Nucleation.

In a Robbins Device, biofilms formed on metal studs such as this one and then they disappeared after exposure to Ice Nucleation conditions.

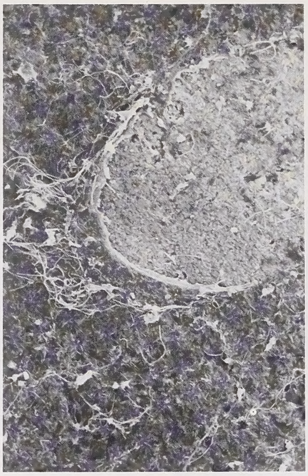
In previous studies it had been noted that large areas of biofilm on submerged rocks and other surfaces in streams disappeared as the stream began to freeze in early winter. This led to laboratory investigations which revealed that biofilm breaks up when its temperature is gradually lowered to 0°C and below. This is related to the fact that "glycocalyx" is highly hydrated; sometimes it is as much as 99 per cent water by weight.

When fouled surfaces of the Robbins Device were slowly cooled to below the freezing point of water, SEM photographs showed the hydrated water was converted to large, sharp-edged ice crystals which severed the polysaccharide fibres. After ambient temperature was restored and water was passed over the thawed film it washed away.

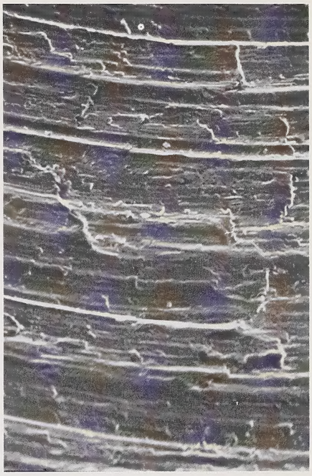
This phenomenon, which is known as "Ice Nucleation", has been induced by cooling fouled pipes from the outside or by flowing cold fluid through the pipes. Fouled pipes that lend themselves to external cooling may be packed with dry ice or be exposed to liquid nitrogen but in complex heat exchanger systems, slow, internal cooling is probably more practical. Generally, this involves using a liquid which freezes substantially below 0°C, for example, 50 per cent aqueous solutions of ethylene glycol or solutions of dextran. After the biofilm is frozen, the ambient temperature inside the heat exchanger is restored and fluid flow is resumed in the system to flush out biofilm that has been liberated from the fouled surface. If need be, several cycles of freezing followed by fluid flow can be used until all the biofilm is removed.



A well-developed bacterial biofilm on a metal surface, representing the interior of a heat exchanger is revealed in an electron micrograph.



After one Ice Nucleation treatment, some of the biofilm has been removed.



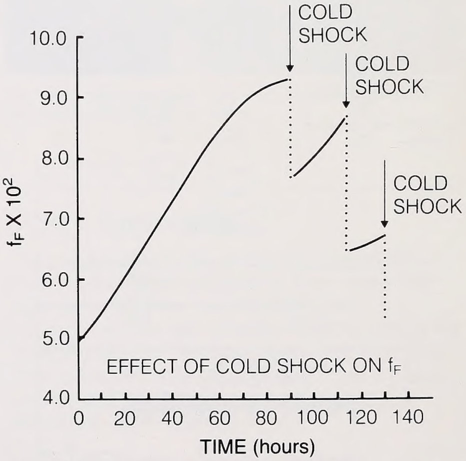
After three Ice Nucleation treatments, biofilm has been completely removed. White lines are scratch marks on the metal surface caused by machining.

On an industrial scale, Ice Nucleation could be achieved by pumping cooling solutions into heat exchangers from a tank truck equipped with a refrigerator unit. As a bonus, the researchers believe this approach makes it practical to recycle the cooling solution. On a smaller scale, Ice Nucleation may be applicable to a broad range of aquatic systems including kidney dialysis machines and systems that supply ultra pure water for the electronics and pharmaceutical industries.

The technique of Ice Nucleation has been patented (U.S. Patent 4,419,248; Canadian Patent 1,161,833) and patent rights were assigned to Alberta Energy and Natural Resources.

Meanwhile, the Robbins Device has gone into service around the world in laboratory assessments of biocides and in field operations where it is typically side-streamed to the exit pipes of industrial heat exchangers.

A modified version has been used to monitor and control bacteria that promote corrosion in pipelines. Other forms of the device have been used in bacterial studies of bulk chemical manufacture, food processing, swimming pools and medical prostheses. Its impact has been felt throughout all areas of modern microbiology.



A plot of Fanning Frictional Factor (f_F, a measure of frictional resistance encountered by fluids) shows friction increases as a pipe becomes fouled by bacteria and then it decreases after each Ice Nucleation treatment.

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Further Reading

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